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ABSTRACT

The Children's Lab at Northern State University (South Dakota) is a science concept development laboratory for use by students in a physical science course for preservice elementary teachers. Its function is to develop science content knowledge in preservice elementary teachers, with the ultimate goal of developing science literacy in children. The theoretical and philosophical bases for the laboratory include (1) the idea that science can be understood only by tracing the history of ideas; (2) work on the structure of scientific knowledge; (3) knowledge of the nature of language and verification; (4) research on developing units of instruction; (5) study of the dynamics of learning and teaching; and (6) work on school science education. The British Museum of Natural History's Hall of Evolution, which traces concept development from simplest beginnings to ultimate implications, inspired this approach. The Children's Lab contains a number of units, each consisting of a series of learning stations at which elementary school teachers are trained to micro-teach about the development of a scientific principle. Students learn meaningful ideas and see how they originated, and are interrelated and applied. The program has been found to be effective, and has the potential for further development for special populations and classroom application. Appended are a discussion of the theoretical underpinnings of the Lab and data from a comparative study of two science curricula. 14 references. (MSE)

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The Children's Lab

at

Northern State University

Elementary Teachers
Moving Toward Scientific Literacy

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AASCU/ERIC Model Programs Inventory Project

The AASCU/ERIC Model Programs Inventory is a two-year project seeking to establish and test a model system for collecting and disseminating information on model programs at AASCU-member institutions--375 of the public four-year colleges and universities in the United States.

The four objectives of the project are:

- To increase the information on model programs available to all institutions through the ERIC system
- To encourage the use of the ERIC system by AASCU institutions
- To improve AASCU's ability to know about, and share information on, activities at member institutions, and
- To test a model for collaboration with ERIC that other national organizations might adopt.

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ABSTRACT

This paper describes the efforts of one science educator to understand the goal of "Scientific Literacy" as presented in the National Science Teacher's Association position paper, "School Science Education for the 70's"; and to take steps to help elementary teachers along the continuum toward this goal.

The author interprets the position paper to be calling for an epistemological emphasis in science education, associates that with the work done by James B. Conant in the '40's and '50's, and attributes the neglect of the excellent resultant programs like SCIS and SAPA, to the fact that traditionally taught teachers were in no way prepared to understand the epistemological shift demanded by these programs.

Steps taken to meet the challenge include the creation of a procedure for identifying and comparing the epistemological quality of elementary science programs, and the creation of science courses for pre-service elementary teachers that help them understand how scientific knowledge is created and established--replicating crucial experiments and recreating the arguments that led to their acceptance. We trace the history of selected scientific ideas from the pre-Christian era to the beginning of the 20th Century. This approach teaches teachers as we hope they will teach. After their course in Physical Science, teachers are required to create their own unit of science instruction in their science methods course following this model.

The Children's Lab is the environment where this teaching takes place. The lab is set up like the Hall of Evolution in the British Museum of Natural History, a carefully sequenced set of learning stations, each building on the ones before. The NSTA position paper is implemented as fully as possible in this lab.

Results have exceeded all expectations. Methods classes have taught hundreds of students in the Children's Lab, and express astonishment at how quickly they learn. My elementary teacher candidates report that they are understanding science and liking it. They are on the move, toward scientific literacy.

Introduction:

The Children's Lab at Northern State University in Aberdeen, South Dakota is a science concept development laboratory derived from theoretical and philosophical premises and implemented empirically by education majors and elementary teachers working with children under my supervision. The goal: scientific literacy.

But the lab is not presently intended for children. Its present functions are to develop science content knowledge in my physical science course for pre-service elementary teachers. They are being taught as I hope they will teach. And the lab serves as a fully implemented model for my science methods students whose major assignment is to create a unit of science instruction on a topic of their choosing in preparation for student teaching.

The theoretical and philosophical premises from which this project is derived include James B. Conant's argument that science can be understood only by tracing the history of ideas; J. M. Bochenski's work on the structure of scientific knowledge; John Wilson's on the nature of language and verification; John Lee on developing units of instruction; Mary Budd Rowe on the dynamics of learning and teaching; and my own earlier work on the National Science Teacher's Association position paper, "School Science Education for the 70's" currently in preparation to be reissued. These ideas are further discussed under "Theoretical Underpinnings." (Appendix A)

The concept development idea from simplest beginnings to ultimate implications is the approach used in the Hall of

Evolution in the British Museum of Natural History. It provided much inspiration to me to complete this project.

Background:

I was a graduate student working with Glenn Berkheimer when the N.S.T.A. position paper "School Science Education for the 70's" was drafted. Berkheimer was one of the architects of that document. The position paper was a superb statement and I supposed it would make a great impact on science education. It did not. It seems to have thrown science education into a tizzy because the document did not include a concise definition of the expression, "Scientific Literacy" - science education's principle goal! After a brief flurry of articles about what "Scientific Literacy" might mean, it dropped from view, the document seems to have been forgotten and even the leadership at NSTA seemed to be wandering around looking for new directions. Last fall Dr. Lamoyne Motte - newly appointed president of the NSTA, visited our campus and advised that the old position paper is in process of being updated for reissue. What became of the impetus of the 70's?

It is my perception that the entire document is a description of "Scientific Literary" and how to achieve it. The best statements I found in the literature came from Robert Karplus and Herbert Thier. Karplus says that "scientific literacy refers to one's ability to use scientific knowledge as though he had obtained it himself." Thier says it means having an under-standing "not only of the basic structure but also of the rationale, and ways of thinking that characterize modern day

science . . . appreciating not only the accomplishment but also realizing the limitations of science and scientists." These statements seem completely compatible with Conant's idea: scientific literacy depends on acquiring an understanding of how scientific knowledge is created - not in vague generalizations like the old "scientific method" myth, but by re-enacting the actual experiments and following the arguments both for and against, that finally resulted in specific prepositions being admitted to the body of scientific knowledge. By so doing, Conant argues, one begins to understand the tactics and strategies of science - to have a feel for what it may and may not be able to know.

The word "science", after all is derived from a Latin root which means "to know" - and the great hope for the 70's was that our students might begin to understand not only what we know but <u>how</u> we know: how those marvelous insights were acquired. The great elementary programs - ESS, SCIS, SAPA, and others were designed to bring this about. But those programs simply did not "catch on" - with teachers.

Elementary teachers were in no way prepared to use them. Because <u>their</u> teachers taught science in massive doses of lectured material - to be accepted by faith - because very little attention was given to how these claims were established. In my own experience, it did not pay to ask how anyone could know that any given bit of science was true. The study of how we know is that branch of philosophy known as epistemology, and traditionally taught individuals are in no way prepared to deal

with it.

I saw a need to do two things: to devise a method for assessing the epistemological quality of elementary science materials, and to tune elementary teachers into programs that are epistemologically strong.

The first task became my doctoral dissertation: "A Model to Facilitate the Assessment of Epistemological Quality in Elementary Science Programs." (Michigan State University, 1974). The study was replicated and validated by Estelle Tafoya at the University of Maryland in 1976. Her simplified model was used by the State of Indiana in evaluating science curricular materials to recommend for adoption. Examples of the kind of epistemological profiles one can draw using this method are included in Appendix B (SCIS vs the text book program, Concepts in Science).

The second objective has been on-going ever since. I have redesigned my physical science courses into units of work, each beginning at the very earliest historical record of anyone's thinking on the subject. I research the topic, write the narrative, recreate the crucial experiments, study the arguments and turn the information into a science course. My physical science students take my science methods course the following year. In this course they create their own units of instruction on a topic they choose following the same model. They are introduced to ESS, SCIS, SAPA, OBIS, etc. and encouraged to draw freely from all sources. They are required to research their topic and write a narrative tracing its history as it

evolved. The students make a considerable investment of themselves in this project, completing lesson plans and developing materials needed to teach them. They can improve these units as long as they choose. If such a grass-roots approach takes hold, we may accomplish what the highly funded excellent programs--thrust on teachers from the top, could not.

Description:

The focus in this program is on the education of the elementary teacher. It is my strong conviction that you cannot teach what you do not understand, and that what you do understand you can discover effective ways to teach.

Present scope of the program is the set of undergraduates in elementary education at NSU. As funds become available, workshops will be offered to selected teachers in area schools--in the hope of developing two very strong science resource teachers in each elementary school. Teachers will be selected on the basis of their own interest in science teaching and the recommendations of their principal. It is my belief that the most effective way to improve the quality of instruction is by the positive influence of individual teachers who enjoy what they are doing and whose students make strong gains in their classes. If it works in this area, it can be replicated elsewhere. Thus, the goals of the program are the NSTA goal of a scientifically literate U.S. population.

The staffing requirements include a person with a strong background in several sciences who can direct the research in the history of various science topics. And preferably some graduate

level teachers who are open to the approach and willing to work at discovering ways to convey ideas to children. One key to this approach is the creation of equipment that conveys a poverful sensory message. For example, in teaching the concept of buoyancy, I use cubic decimeter blocks of many different types of wood. We observe how they feel and how they float, how much water they displace and how much they weigh. When we explore density formally we continue to use cubic decimeter blocks--only this time, of aluminum, lead, and copper. The sensory experience makes an impact. One 4th grader spent half an hour on the telephone explaining density to his father in California. The idea is clearly understood and the language including the mathematical ratio that describes it, become working tools for these students. We develop the metric system after students have worked with these cubes until they are comfortably familiar objects.

Creating teaching materials demands access to tools, shops, and industrial arts expertise; an industrial arts person is indispensable to this project. Some one must maintain the lab, keeping it available at user's convenience, for the best way to "fix" these ideas is to teach them to someone else. The lab finally needs continuous evaluation and promotion.

Costs:

Funding to date for the Children's Lab has been limited to a $1500 Grant from First Bank of Sioux Falls that got it launched originally as a project for area Girl Scouts, followed by a Title III Grant through NSC in the amount of $23,000. This money

replaced old equipment and provided some released time for the director to create new units on Air and Air Pressure, and Electricity and Magnetism. As effective teaching techniques are developed and proved, additional funding and space will be needed to provide work stations for classroom groups.

Development and description of the buoyancy unit are as follows:

A DESCRIPTION OF THE LAB

In the actual design of the lab, I decided to follow the recommendations of John Lee, author of Teaching Social Studies in the Elementary School. In his chapter on unit development, he recommends that you first gather a file of all the good stuff you can find on the topic of interest, study it and then write all you know on the subject yourself, in the clearest language and best organization you can muster. This he calls the "concept clarification" - the teacher's best way of making sure the ideas are all clear and interrelationships well understood in his own head. After necessary corrections, additions, deletions, and several rewrites, the concept clarification becomes the guide for selecting the appropriate content to be taught to a given group of students.

I next highlighted all the words that I thought my students would not have meanings for and set about to discover activities that would provide them. Some equipment had to be designed and gathered; some items had to be specially made. A trial learning sequence was decided upon and my first experiment was underway with my undergraduate science methods students. They were

enthusiastic, gave valuable feedback and contributed much to making the learning stations both more attractive and more functional. The sequence of learning stations underwent several revisions. We invited sixth graders from a local school and my students were amazed at how interested they were and how quickly they caught on. Then, we were ready for the Girl Scouts. Sioux Falls College provided an ideal room for the lab, and the Girl Scouts came, over the next two semesters, more than 300 strong. The lab stations have continued to evolve and grow, but the basic sequence of ideas has remained pretty much the same ever since. We have experimented with times, group sizes, and teacher-pupil ratios.

Of the various arrangements we have tried, the best by far was when children came to the lab for two-hour sessions over five consecutive Saturdays. Each of my students was assigned to micro-teach two or three children from grades four, five, and six.

Ideas developed at the lab stations are as follows:

STATION 1. The same object can both float and sink. We do this with vinegar and soda and raisins, each child observing his own system, formulating complete statements to describe what he observes and what he thinks is going on. Most children come to the lab supposing that an object either floats or sinks, as their first grade science lesson teaches. Station 1 "offends their intuition" and generates lots of interest. It is one the students love to repeat at home.

STATION 2. As a floating object goes down into the water, the water level rises and as the object is lifted out of the water,

the water level falls. Children quickly relate this observation to the behavior of the see-saw and the balance. One session exploring this station enables them to discover that a floating object is like a balanced see-saw, the object on one side and its displaced water on the other. They formulate an accurate statement of this relationship.

STATION 3. At Station 3 we invite the students to empirically verify the relationship formulated above. Five cubic decimeter wooden blocks of varying densities are compared and set afloat in separate overflow tanks. The displaced water is caught in liter boxes and compared with the weight of the displacing block. By the completion of this experience, the students have a firm grasp of buoyancy: an object that floats will displace its own weight of water.

STATION 4. At this station, we take up a new situation. Instead of working with cubic decimeters of wood, we use cubic decimeters of aluminum, and discover what happens when objects sink. The aluminum cubes are weighed in both air and water and students discover that each cube seems to have lost 1 kilogram of weight. They formulate accurate statements like:

a) "If an object sinks, it will displace its volume of of water, but not its weight."

b) "The aluminum cube displaced 1 cubic decimeter of water."

c) "The displaced water is pushing the cube out with a force of 1 kilogram."

d) 1 cubic decimeter of water weighs 1 kilogram."

e) "If a cubic decimeter of something weighs more than 1 kilogram, it will sink; if less than 1 kilogram, it will float."

(At this point, we introduce the term "density" an some history of the metric system.)

STATION 5. At Station 5 students handle cubic decimeters of aluminum, copper and lead. We ask them to come up with a mental model to "explain" how three chunks of matter of the same size and shape can have different weights. We develop the notion of population density by standing in squares of various sizes on the floor. They are usually familiar with the expressions "dense fog" and "dense forest". They invariably begin to think in terms of "packing" to explain the density of the cubes.

A favorite activity for many students is to determine the density of various types of wood blocks using a metric ruler, triple beam balance and calculator. They enter their calculations and compare them to those of students who have done this before.

STATION 6. At this station students are given balls of plasticene and challenged to make them float. They discover that even though plasticene is denser than water, by changing its shape it can be made buoyant. Sheets of lead are treated in the same way. Students discover that the principles of buoyancy can be maximized by the technology of shaping.

Students compete at this station to see who can design and build the paper boat that will carry the greatest payload of marbles.

STATION 7. At this station students explore the effects of floating objects in liquids of different density. They can predict from their knowledge of density, what will float in what, and what to expect of boats as they move from salt to

fresh water.

STATION 8. At Station 8 children create and explore their own Cartesian divers. By careful observation they can essentially describe Pascal's Law, and interpret the diver's behavior in terms of the basic principle of buoyancy.

STATION 9. At Station 9 we examine buoyancy in marine animals and plants.

STATION 10. This station examines the application of buoyancy to objects that float in air.

In addition to the ten basic stations, social studies implications of this principle may be explored in terms of where civilizations have developed, how goods are moved, and how control of waterways may become a matter of international conflict. Another station features songs and stories of rivers and seas, with filmstrips, cassettes and books. A station on specific gravity and use of the hydrometer to determine concentration of ethylene glycol has been set up, but seldom used with children. The ideas are beyond most children we have worked with.

The primary emphasis in every unit of this lab is to help students develop meaningful ideas, to see how they originated, and to see how they are interrelated and applied. Unrelated bits and pieces is, by definition, confusion. The more integrated our learning becomes, the more powerful it is for whatever uses we choose to make of it.

Units of Air and Electricity and Magnetism are developed in the same way. They are far more complex.

Results: External Evaluation

The following report was made by our External Evaluator, Dr. Michael R. Dingerson, Associate Vice Chancellor for Research, and Dean of the Graduate School, University of Mississiopi, October, 1988. The Children's Lab is described as "Activity II" among other Title III projects at Northern State University.

Activity II - Improvement of Academic Programs--Elementary Science and Learning Laboratory.

The major objective for this activity for 1987-88 was to improve the understanding of scientific principles by incorporating elementary science laboratory experiences into the curriculum. The materials have been ordered and assembled and are housed in a very attractive facility in the science building at Northern. The curriculum on buoyancy and air for the elementary teachers has been completed and is available for inspection. The evaluator had a chance to proceed through the step-wise process on the buoyancy curriculum to gain an appreciation for its philosophy and its actual experimentation from the simplest to most complex issues. This is a particularly attractive laboratory and learning center because it teaches and challenges its students to understand the basic concepts of a scientific principle while adding a bit at each stage to allow the student to build on earlier learning and to advance to more complex stages in a short period of time. The strength of this approach is apparent in that the student learns to think about the problem and to solve it in a way in which the concepts are incorporated into that student's thinking process rather than to have the student memorize a formula or a behavior which later

must be applied.

The evaluator had a significant amount of time to talk with the coordinator of this activity and was impressed with his approach philosophically, with his energy and enthusiasm about this effort and with his ability to carry forward with this activity. This is a very important activity for the institution and one which should be disseminated more broadly to other schools for consideration.

This activity is on schedule and under excellent guidance.

Results: Internal Evaluation

Evaluations of many kinds have been an ongoing part of the lab's growth and development since its earliest beginnings. Since the aims of the inquiry approach to science teaching is to help kids do science pretty much as scientists do it, and since as Bochenski has put it, the ultimate aim of every science is to establish true statements, (Bochenski, p. 7) our first criterion of evaluation has been whether, in fact, elementary children can formulate significant true statements about the natural phenomena encountered in the lab. Our success here has been phenomenal. Because the ability of a group of youngsters to make accurate observations is phenomenal. When they understand that our primary objective is to describe, not to explain, they are remarkably capable of describing, in their own words for the most part, what they observe, and of associating the phenomena with similar ones from their own experiences by way of analogy. They further hypothesize about correlations and respond with very good ideas to the question, "What would convince you that this is true?"

Mary Budd Rowe's ideas, her sense of what constitutes success in education, and the hard data she gathered to show how it can be achieved, are the models we followed for evaluation. Success is measured in terms of how much content relevant speech is generated among the students as they interact with materials. And, one remarkably simple technique for achieving it is to simply give kids time to formulate thoughtful answers to appropriate questions.

The evidence of success in any educational endeavor is the extent to which the teacher can engage the child's mind, and emotions and senses, positively in the context of the chosen subject matter. By this criterion, the Children's Lab is highly successful with children. Initially, we paired two elementary teacher majors with each group of ten children. They wrote the students' statements as they were formulated, and we collected a mass of data. It was a constant battle to get complete statements. Some children seem never to have been required to formulate complete statements before. But, we do succeed. Here are some examples of their efforts:

"The raisin needs a lot of air bubbles to come up. Less bubbles (1 or 2) to go down."

"The boat will sink if it is heavier than the displaced water."

"An object that floats weighs as much as the water it displaces."

"When an object sinks, it will lose the weight of its volume of water."

"Each material has its own ratio of weight to volume."

"Dense means a lot of particles in a small space."

"An object that is less dense than water will float."

"Clay has to be in a certain shape for it to float."

"By changing the shape of the lead boat we displace more water.

"Salt water is more dense than fresh water."

"When you squeeze air together, the air gets more dense."

"When Pinocchio floats, he displaces his weight. When he sinks, he displaces his volume, due to air compression." (I used a Pinocchio figurine in a Cartesian Diver)

Children as young as six and seven years old (1st graders) have done parts of the lab. All groups who have worked in the lab have demonstrated their ability to orally formulate true statements, i.e., to create fundamental pieces of scientific knowledge. When we were convinced of this, we began to experiment with having students attempt to <u>write</u> their own statements. I personally began to realize what a terrible hurdle writing is for children and why teachers finally settle for short answer tests. But, when children are given less than one second to formulate a verbal response, and are restricted to circling the correct response on written tests, they have almost no opportunity to demonstrate what they are intellectually capable of doing. The fun is gone out of education, kids tune out, and teachers burn out. But, it need not be this way.

Convinced that children can grasp ideas and formulate them into meaningful statements, we directed our efforts at getting, in addition, some written responses. We designed a comprehensive test that included all the science experiences covered in the lab. We first gave this as a pre-test and a post-test to about 250 Girl Scouts, ages 8-11 from Sioux Falls and surrounding towns. The Scouts received an average of 90 minutes hands-on

experience and instruction in the lab.

The early part of the 25-question test deals with observations students might have made from common experiences. The mid-portion deals with the principles developed in the lab, and the latter portion with application of those principles. Post-test scores showed a 20 percent average gain, heavily in the mid-portion of the test. We were pleased with their gain. We were also aware that many students missed questions because the wording was difficult, not because they did not understand the principles involved.

We next created a set of post-tests for each station and tested these in the spring of 1984 with about 50 sixth graders from Horace Mann Elementary School in Sioux Falls. These students came for a series of five visits, one each week at 45 minutes per visit. The pre-test was dropped and station tests given at the completion of each station. Pairs of preservice elementary teachers were assigned to teach a group of ten students. The post-test scores mean was 66 percent. Thus, students demonstrated on a short answer test that they grasped about two-thirds of the ideas we presented. The range of scores was quite narrow suggesting that the effect of differences in teacher ability on what students learned is minimized. There were significant differences in the classroom performance of the teachers in this group).

One month after their last visit to the lab, I showed a set of slides of the lab stations to these same students and asked them to write what they learned at each station. Their

answers were revealing and encouraging. Lack of skill in writing and spelling is appallingly evident and there were many non-sentences, but every learning experience registered, some with only one or a few, others with many. Here are some statements from student papers on this follow-up test:

"Almost anything can be made to float. Baking soda and vinegar mixed together cause a reaction. The reaction is put to use by making the raisins float."

"The pan displaces just the same amount of water as its weight and that's how it floats."

"When the block is placed in the water its displaced water goes out into the container. You pour water in another container to equal the weight of the cube. You compare the two containers and it tells you that anything that's put in water will displace its own weight."

"The jug looks like it would be really light, but its really heavy because it holds a lot of water."

"Water is very heavy."

"I learned about buoyant force. When you try to push something in the water, the buoyant force pushes back."

"Only bowl shaped things float."

"The heavier the block the more water it will displace. The block displaces its own amount of water."

"The amount of space taken up equals the amount of displaced water."

"The [aluminum] block equals the amount of water in <u>volume</u>."

"The block weighs less under water. When we weigh on scale it weighs 2.9. When weighed in water it weighs 1 kilogram less."

"The cube weighs less because the buoyant force pushes it up."

"The cube went under water completely. The displaced water in the box, its volume is the same."

"Sorry, didn't see this. But did they measure the length of the cube?"

"b x h x w = volume"

"They put the same amount of water in the (plastic box) as the [brass] weight weighed."

"Each cubic cm weighs a certain amount."

"When molecules of an item are spread out the item weighs less. We talked about dense or densely populated areas."

"If you densed the ball of clay together it wouldn't float, but if it was like a bowl it would float."

"We shaped the lead like a boat and it floated."

"Almost anything can float in mercury."

"We sell up the air suple and puppte will sink. Puppte nend air to float."

The last statement is the poorest of English, but represents good understanding of the Cartesian Diver. The Children's Lab works very well with children.

This group of sixth graders was taught by undergraduate students in my science methods course. Each pair of undergrads was assigned to work with a graduate student. All the graduate students are certified teachers with experience. The graduate students observed that we expect a lot from these preservice elementary teachers. It is their first teaching experience. The material is new to them. The content is moderately difficult science. The methodology is "far out" and they have no idea what the children are like until they arrive--quite excitedly --for their first lesson.

Some consequences were:

All the teachers were nervous, some were weak on their own understanding. "Lights" were still going on for some, three-fourths of the way through the teaching experience." All needed more work with questioning techniques. Some inaccurate statements slipped by, both from children and from teachers.

Some confusing test questions were discovered.

At least one teacher discovered that she did not want to continue in elementary education.

Most teachers expressed their own desire to be much better prepared to teach.

Some concern was expressed about children who were placed with weak or uncommitted student teachers. But, all agreed it is an excellent learning experience for all preservice teachers and especially for those children whose teachers were well-prepared.

Lab teaching is done outside of class time and even conscientious students sometimes find it difficult to schedule sufficient practice before teaching. Some at the outset are unhappy with this teaching requirement, but student evaluations of the lab teaching learning experience are over-whelmingly positive. And, we have documented cases where children got ideas straight even when the teacher didn't understand. There is a much greater chance for this to happen in a hands-on situation than with a textbook in the classroom.

Final exam essay-type questions on the concept of buoyancy show that my college students in the spring of 1985 finally grasped the cluster of ideas very well. They both drew accurate diagrams and also wrote clear explanations of what happens in the lab. They were, in addition, asked to keep a journal and write an evaluation of their experience of teaching children in the lab. Some representative comments from journals follow:

"When I don't say very much, they talk about what they see, and they toss different ideas around and tell each other if they agree or disagree." - Tammy

"My problem was letting kids <u>discover</u> why raisins rose and fell instead of telling them." - Jan

"We realized we needed more practice in the lab and more preparation." - Pam

"I saw the fun, excitement and relevancy of hands-on science. I gained respect for the students. I also gained respect for the teaching profession." - Brenda

"Its really interesting to see the change in Chelsea. While her spelling and writing are not good, she can tell us what is happening." - Deb

"I was amazed at how fast Chris and Chad figured things out. But Chris was frustrated because he had trouble writing things down on paper." - Dawn

"The most interesting thing I learned is that these kids catch on really fast. Children are very descriptive. And I talk too much." Tina

"I made the mistake of including volume in a station that was only supposed to deal with weight. My mistake caused much confusion in all the students." - Willie

"Heather and Josh seemed to catch on fast." - Karen

"Good smart kids!" - Tracy

"They caught on quickly. It was hard for them to make complete statements, but once they did, they were good statements."

"I feel the kids are learning in spite of our goof-ups."-Emily

"Nathan does not say much, but seems to have a better understanding than Karissa who wants to do all the talking."-Emily

Comments from their evaluations of the lab follow:

"I will admit I was a skeptic about how much these "young-uns" could actually learn about displacement. They continued to surprise me with what they could comprehend. The biggest thing I learned was that I can't put a limit on what these students can learn. They excelled far above the level of my expectations." - Pam

"I learned a lot through these lab experiences. Most important: preparation beforehand is absolutely necessary. As I taught the kids I understood the concepts better myself. I learned that you can't teach unless you know what you're teaching."-Emily

"It was fantastic to see the face of a child light up when they understood what was happening." - Cindy

"I needed to actually see the children teach themselves through the lab stations and through their own interest and excitement.

"A teacher who lets the students make their own statements about what's happening enables the child to know if he understands and also shows the teacher that he has grasped the concepts." - Darla

"The lab gets the kids' creativity flowing! This has to be one of the most effective ways of teaching." - Tracy

"You know the kids have successfully grasped the concept when you hear it coming back to you in their own explanation."

"It made me feel good when the kids felt free enough to say, 'Then I guess I really don't understand.'"

"Underestimating kids is a big mistake." - Lisa

"When the children were learning and doing they were not behavior problems." - Donna

"The buoyancy lab was one of the best experiences I have had, not only for teaching science, but other subjects as well." Chris

"They all worked until they had a successful outcome. I learned to look at each station differently after hearing their statements. I learned more about buoyancy from listening to the girls and their comments. I feel good about what we accomplished." - Judy

Other groups have used the lab. We have run a series of summer workshops for teachers that are becoming increasingly well attended. Workshop participants have been especially appreciative of what they learn. Some comments are as follows:

"I was made more aware of the power of language."

"The explanation of why things happened was often a blank until I realized I could try to explain it just by use of my own knowledge."

"Most importantly, I learned to think."

"There was no wasted time. That in itself was a good experience.

"This has been the best workshop for information I have had.

"I learned that things that seemed so hard can be made easy-like Boyle's Law."

"This class even helped us put ideas into succinct language-

language that said what we meant."

"It is the most basic teaching I have ever seen--nothing is assumed."

"Everything we did . . . I can use or modify to use in my chemistry and earth science classes."

"I can never remember learning so much about science in such a short time."

"I feel that I have gathered some ideas I can use in Social Studies."

Finally, many groups have come for a "walk through" of the lab. Such visits are of limited value. Inquiry science only "works" for people who are willing to interact with the phenomena of nature, and then express what they experienced in statements. This is, indeed, what science is about.

CONCLUSIONS AND RECOMMENDATIONS

This program has been remarkably effective. It is derived from a very strong philosophical and theoretical base and it has been fine-tuned with teachers working with children.

The Children's Lab is a natural setting for further research on learning. It has yet to be opened to hearing and vision impaired children, children with reading problems, and minority/culturally different children.

I need to conduct a survey of teachers who have been trained in the lab to see if and to what degree their experience has influenced their own classroom practice.

Teachers may need help in adapting work stations to learning centers. Ways to find space in elementary classrooms and to replicate good teaching materials must also be explored.

The most critical needs for the project's continued development at Northern State University are released time for the director, and graduate students interested in pursuing the development and implementation of new units. An especially urgent need exists for a unit in Anatomy/Physiology and Health. And the lab requires more space. It now has one classroom for work stations plus a prep/storage room. This provides enough space to set up ten work stations as learning centers, but only 3-5 students can work at a station at one time.

Funding for the program has been adequate to make it operational. The process is by its very nature, slow. There are no guarantees in either research or in development and testing of materials. For this and other reasons, it is best kept a "grass roots" operation. However, a network of interested "grass roots type" science educators would greatly move this effort along. What has been done to date could easily be replicated at any institution that would provide space and equipment and leadership for it.

The Children's Lab at Northern State University is open for dissemination of information, for research, and for input.

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APPENDIX A

THEORETICAL UNDERPINNINGS - CONANT

The theoretical underpinnings of the lab go back to my own undergraduate education when I was a chemistry major at the University of Louisville, Kentucky, much more interested in how things can be known that in what people claim to know. My major professor put me in touch with Dr. James B. Conant and his writings, opening a whole new world to me. Conant, organic chemist, former president of Harvard University, Head of the Atomic Energy Commission, Ambassador to Germany (and how many other superlative distinctions I cannot tell), proposed quite simply that:

A. Scientists approach their work from a certain "point of view."

B. That this "point of view" exists quite apart from the knowledge that they generate (and cannot be discovered through that knowledge even by mastering great quantities of it).

C. That the best way to acquire this point of view is to reconstruct the precise history of how specific bits of knowledge were created.

D. And finally, that it is the very simplicity of early formalizations of knowledge that enables us to grasp the scientific point of view which remains unchanging over time, though now undiscoverable in the extreme complexity of the knowledge currently being created.

Now, boats are as old as human civilization and the basic principles of buoyancy were formalized by Archimedes in the 3rd Century before the Christian era. The most fundamental ideas in the physical sciences--weight, volume, density, displacement, shape and measurement--are discovered in exploring why things float and sink. So, "buoyancy" was a good choice from Conant's perspective for helping students to begin to grasp the

scientist's point of view.

Conant's objective in developing this approach was not to create scientists, but to provide for the general education of layman for active participation in a democratic society. The Harvard Case Histories in Experimental Science, a two-volume work, is available now as an expression of his influence and his deep conviction of the validity of this approach.

I know of no finer starting place for anyone interested in this kind of science education. The current popular work of Thomas S. Kuhn, The Structure of Scientific Revolutions, is a further elaboration and outgrowth of Conant's work. Inherent in this approach is the notion that we only grasp what is truly important about science when we see the basis on which belief systems have developed and changed, i.e., when we begin to understand how scientific statements are verified.

BOCHENSKI

A second strong influence in the design of the Children's Lab is the work of philosopher and logician, J. M. Bochenski, entitled, The Methods of Contemporary Thought. Bochenski looks at science from the perspective of statements and their verification, and while warning of the enormous problems in this field, he proceeds to greatly clarify the nature of scientific knowledge by describing the kinds of statements is contains, when classified on the basis of how they may be verified. In so doing, Bochenski relates sensory experience, meaning, and verification and clears up some problems that have defied philosophers for centuries. He sees language as the place to

start because inhis words, "Every science strives to establish true statements: that is the ultimate aim." He further affirms that "the truth of a sentence must be either apprehended directly, [i.e., by sensory experience] or inferred: there is not, and furthermore there cannot be, any other way." So, there are only two methods of verification for statements, which give rise to exactly four kinds of statements, and the four kinds of statements constitute the entire body of scientific knowledge. He names and describes them as follows:

1. PROTOCOL STATEMENTS. These statements describing what someone has "apprehended directly" by immediate sensory experience. They refer to the content of that single experience exclusively, and verification of such statements is the experience itself to which this statement uniquely refers. Such verification says Bochenski, "is incorrigible...it is impossible to be mistaken about it except in a verbal sense." Carefully kept records of such experiences, including circumstances, date and time, place and observer's name, etc., constitute the hard evidence which from an epistemological point of view is the foundation of the system. Theoretical elements play a secondary role. Protocol statements ultimately determine the admissability of other elements to the system. Anything inconsistent with protocol statements must be set aside... Anything which serves to explain those statements is admitted." In more familiar words, observation described in precise language are the things about which we can feel quite certain in the body of scientific knowledge.

2. GENERAL STATEMENTS Despite all their certainty, protocol statements are of little consequence unless they can be generalized. The fact that something was observed one time, however remarkable the event, is only of curious interest. We want to be able to say, whenever such and such conditions prevail so and so can be expected to result. Yet, in the very act of formulating the generalization, we move from the kind of statement that can be known with certainty to a new kind of statement that must be forever uncertain. All generalizations go beyond the the evidence, describing not only what is, but what has been, and what shall be. And as stated by Hospers, "It is logically impossible to know the truth if any statement involving the future...[thus] we cannot know that any law of science is true." (Hospers, p 169). Or, in the words of Glen Berkheimer, "empirical knowledge by its very nature is inconclusive because it is impossible to observe all possible cases." (Berkheimer, p 41). Scientific laws are, in the final analysis, statements of empirical probability created by a thought application process known as "induction" of which Bochenski says:

> "The great work achieved by induction appears to the logician like the successful deciphering of a text in code to which we still lack the key. That some things have been decoded seems certain: it is just that we do not know how this has happened." (Bochenski, p. 114)

Finally, with respect to both the protocol statement and the general statement, the conditions under which the event took place must be very precisely described, for the slightest difference in a single variable can drastically alter the results. Protocol statements and general statements differ significantly in just one way. One refers to a single event, the

truth of which can be virtually certain; the other refers to all possible events of that kind and we can never be sure it is true. But, protocol and general statements are alike in other respects. Both describe interactions among nameable physical objects and both describe phenomena that can be observed by the five senses. Hence both are expressed in the same kind of language vocabulary.

3. THEORETICAL STATEMENTS. The third type of statement Bochenski describes is radically different from the first two in that it is concerned exclusively with the mental models we create to explain the uniformity of the physical world. These are called "thecretic" statements and they name and describe things whose existence can only be inferred, that are not physical objects we can perceive by our senses. Atoms, electrons, gravity and genes are examples of such "things". We cannot know anything about such things by direct sensory experience. All that we can know about them is to be learned by examining the history of how they came to be, and what protocol statements and what scientific laws they were invented to explain, and whether or not they do in fact explain them, i.e., simplify and integrate the great masses of diverse information contained in protocol and general statements. If they, in addition, help us to make non-trivial predictions that can be observed true back to the sensory level, then theoretical statements become valuable guides to continued scientific exploration. They give us helpful ways of thinking about the world and it is not terribly important to know if they are true. That is fortunate, for there is no way to find out.

In summary then, the structure of scientific knowledge

rests on the solid foundation of protocol statements. The next level above protocol statements is composed of generalizations known as scientific laws. And the top level consists of theoretic statements--descriptions of our ways of trying to organize and simplify the vast amount of otherwise unrelated information about the world, by creating mental models in the process known to philosophy as reductionism.

4. ANALYTIC STATEMENTS. There is yet a fourth kind of statement that concludes the list. These statements give us no information about the physical world, but only about how we have agreed to use words. They must be included however, simply because we use words to formalize scientific knowledge. These statements are called "analytic" statements and their distinguishing characteristic is simply that the subject and the predicate mean the same thing. Thus, they can be verified simply by using the dictionary, and they are called "analytic" statements because their verification consists exclusively in an analysis of the words they contain. No examination of nature or logic is required. An example of such a statement might be, "Invertebrates do not have backbones." Analytic statements are extremely deceptive at times. Much of what passes for scientific knowledge is in reality knowledge about the ways in which we have agreed to use language.

What, then are the implications of Bochenski's work for science education? First off, science teachers need to understand what kinds of statements we can know with certainty, what kinds of statements we accept on the basis of probability, and what kinds of statements we accept because they organize and simplify

and give direction to exploring an otherwise overwhelming amount of information. If the warring factions in the textbook controversy could understand this much, a great deal of energy and resources could be directed into more profitable activity. Secondly, when children have hands-on access to the phenomena of nature, they are astonishingly capable of making accurate protocol statements. In so doing, they are creating the very foundation of scientific knowledge. Further, they are capable of making general statements and of designing experimental procedures for verifying them. They identify the variables, recognize the need to control them, carry out investigations, and interpret outcomes. And, in all of this, a great deal of language is learned. It is my own belief that theoretic statements are inappropriate until the force of the evidence and reasoning that led to their formulation can be felt and understood by the student. Most theoretical knowledge in science belongs in secondary schools and beyond. Elementary school is the place for children to begin to explore and describe phenomena, and to build the foundations of scientific knowledge.

WILSON

A third major influence behind the Children's Lab is the work of John Wilson, extending Bochenski's work on language and verification. His little book, Language and the Pursuit of Truth lays bare some of the most profound, yet obvious, truths about the nature of language, beginning with the nature of words, and why we are able to use words to communicate. The great motivation behind this book is a conviction that all the problems facing

humankind must either be undertaken with words of understanding, or by compulsion and violence. And the discovery of truth is especially dependent on our understanding the notions of "meaning" and "verification". Here is Wilson's basic premise.

> Words are like all other artificial signs: a gesture, like nodding one's head to indicate agrement, or shrugging the shoulders to convey indifference. The dots and dashes of Morse Code, the flag positions of semaphore, the flashing red light at the intersection, the ringing of a bell, or the column of white or black smoke eagerly awaited by the crowds at St. Peter's Square--all of these artificial signs, like words, have no meanings in and of themselves. They are effective for communication only because people have agreed to use them in certain ways. Thus, it is our agreement about its use, not the sign itself, that enables us to communicate by signs. It is our agreement about its use, and not the word itself, that enables us to communicate with words. I say again, words do not have meanings. Words cannot transfer meanings from the teacher to the students or from the textbook to the student. Nor can pictures, and while a picture may well be worth a thousand words, even "pictures can only serve to remind us of experiences we have had." (Walton, 1973, p. 300)

If I have a meaning and you have a meaning and we have chosen a word to designate that meaning, then that word is useful to us in communication. But words can only help us communicate about meanings we already share. If either of us lacks the meaning, the word can do nothing to put the meaning in our mind. Yet, we have assumed that students can get meanings

out of words, and have turned our whole educational system into what is often nothing more than empty verbage. I call it "wordgebra"--you know, what is another word for ___? Most sadly of all, knowing another word for it seems to be our single-most trusted measure of whether a student has learned or has not learned. What we most desperately need are methods of showing teachers how to find and create meanings for students--and for themselves. Meanings come only from sensory experiences and our reflections on them. It is these experiences and reflections that create the need for language and language must be developed in conjunction with them, if we are, in fact, to be able to talk about what we know, and to know what we are talking about.

The job of education must go beyond the business of charging our children with empty verbalisms. The Children's Lab is an attempt to create meanings through sensory experiences to which functional language can then be attached. Only meaningful language is useful in practical problem solving.

But, Wilson offers one more phenomenal insight to learning: he provides a practical solution to the problem of verification. The traditional philosophical stance has demanded that three conditions be met. We can claim to know if and only if (a) what we claim to know is, in fact, true; (b) it is based on good evidence and (c) it is believed by the one who claims to know it. Bochenski's insight was just that the four types of scientific statements each has its own unique method of verification, and the degree of confidence we can put in each differs. Wilson's insight was that verification is ultimately a personal matter,

and the three practical conditions that must be met are as follows. The first condition is that we discover the intended meaning; i.e., what the statement maker is trying to accomplish. If he is making a knowledge claim we can proceed. Secondly, we must individually decide and then agree beforehand on what we would accept as verification. And finally, we must consider the evidence and make a decision. Wilson is very strong on this point. By way of further clarification he states:

> "We can logically compel someone that what passes the verification tests for being red is actually red. But, we cannot logically compel him to agree to accept the verification tests themselves." (Wilson, p. 89)

Carnap concurs, stating:

> "...everyone is free to decide what kind of verification he intends to allow...but he makes clear that in the sciences, statements must be 'ultimately verified by sense experience'". (Quoted in Bochenski, p. 56)

This approach makes every person responsible for what they believe. Children respond very actively to this challenge and become involved in amazingly complex arguments that display an exciting level of seldom tapped cognitive ability. Students that get involved in this kind of activity are doing what the NEA and the NSTA have been calling for over several decades. They are learning how to learn.

ROWE

A fourth person whose influence is strongly felt in the Children's Lab is Mary Budd Rowe of the University of Florida, and her science methods textbook for elementary teachers. Rowe is the most dedicated and competent person I know of in the implementation of inquiry teaching in the elementary classroom.

She maintains that the critical issue in education is the student's attitude toward change. Some students believe they can influence the direction of change and others do not. The first group she describes as bowlers, the second as crapshooters, and she designs curriculum to help all students balance these opposite tendencies, and develop a realistic attitude toward fate control. She begins with the idea of systems and variables, for when you learn to manipulate the variables, you gain some control of the system and you can influence outcomes to be more favorable than they might be by chance. Mary Budd Rowe see science education as a marvelous avenue for teaching children about fate control, consequently about <u>hope</u>, and about language. Her tape recordings of more than 800 sessions of traditional classroom instruction in science led to the astonishing discovery that in a 40-minute class period, the average teacher asks between 120 and 200 questions. She also discovered that the teacher waits on the average, nine-tenths of one second for students to answer. The same studies document that some teachers spend as much as 25 % of all their talk in praising and blaming. Clearly, there is little chance of engaging the child's mind in a meaningful way about the subject matter when class is conducted like this! Rowe's research is the strongest argument I know of for inquiry teaching and learning, and her recommendations for correcting these appalling situations have been demonstrated effective.

APPENDIX B

APPENDIX B

Comparison of "SCIS" and "Concepts in Science" profiles of sentence types taken from comparable topics in each program.

The SCIS Profile (845 sentences analyzed)

Non-assertion accounts for 62% of the total sample. The remaining categories are rank ordered by percentage of the rest of the sample. The percent shown is the number of sentences in the category over the number of assertions inthe sample (323), to the nearest whole percent.

Not science subject matter	29%	Not fully explicit	4%
Analytic (word meanings)	28%	Subjective	3%
Epistemological	18%	Theoretic	2%
Synthetic	12%	Non-Cognitive	0%
Knowledge how to do	4%	Wording not consistent	0%

Concepts in Science Profile (552 sentences analyzed)

Non-assertion accounts for 43% of the total sample. The remaining categories are rank ordered and percentages calculated as above.

Concepts in Science Sample Profile

Theoretic	20%	Wording not consistent	7%
Synthetic	15%	Non-cognitive	7%
Analytic	13%	Problems	5%
Pseudo-Protocol	9%	Epistemological (non-theoretic)	4%
Make-Believe	9%	How to do	3%
Not Fully Explicit	8%	Not Science	1%
		Overtly Subjective	1%

From "A Model to Facilitate the Assessment of Epistemological Quality in Elementary Science Programs" unpublished doctoral dissertation by Paul K. Knecht, Michigan State University, 1974.

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